STATUS AND SUMMARY OF TEST METHOD STANDARDIZATION OF ADVANCED COMPOSITES IN JAPAN

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Keywords: *Composites Database, Building Block Approach, Mechanical Properties Interlaminar Shear, Open Hole Compression*

Abstract

Standardization activities of test methods of composite mechanical properties in Japan are reviewed and summarized. Three methods, interlaminar shear by double notch compression, open hole compression and open hole tension are being standardized into JIS, Japan Industrial Standard. In the latter two items, different methods from the current de facto standards are proposed and evaluated. Proposal activities of composite test methods from Japan to ISO, International Standard Organization, are also reviewed.

1 Introduction

Advanced composites are considered as substantial materials only by which the newly developed aerospace vehicle can be feasible[1)]. It is well known that new Airbus A-380 and Boeing 7E7 will utilize a great amount of advanced composites. However, a route for the validation, evaluation and certification of composite aircraft structures, so-called building block approach, is quite different from that of traditional metallic aircraft structures and an importance of composites database is now well recognized[2)]. In order to construct fully descriptive and reliable composite database, the key issue is to establish standard composite test methods. Thus, standardization of composites test methods becomes very important technological field in aerospace composites research. In Japan, some basic testing standards of composites such as tension and compression of unidirectional materials are already defined and proclaimed. However, most practical portions of testing standards of composites are not defined yet and strong demand of such standards has been arisen recently. Hence, Institute of Space Technology and Aeronautics (ISTA) of Japan Aerospace Exploration Agency (JAXA) started sponsorship and operations of definitions of practical test methods of composites frequently used in building of their database. The present paper reports a current status and summary of such activities.

2 Background

2.1 Increase of Composites Applications to Aircraft

Advanced composites appeared after the invention of carbon fiber at 1967 and gradually penetrated into aircraft material market. Figure 1 summarizes such trends as the ratio of advanced composites (mainly carbon/epoxy) weight to the whole structural weight of aircraft. As shown there, recent commercial transports utilizes great amount of composites like 23 % in Airbus A-380 and 50 %! in Boeing 7E7. Material application diagrams in Airbus A-380[1)] are shown in Figs. 2 and 3. One feature in this aircraft is an application of fiber-metal laminate considered as hybrid composites, GLARE®. In Fig. 3, a sum of composites (carbon/epoxy) and GLARE® looks 20 %, although a recent report

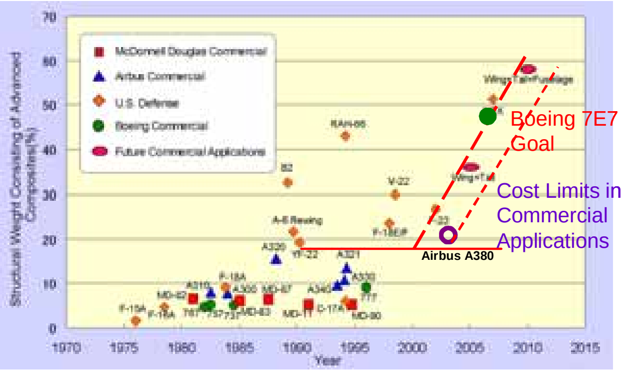


Fig. 1 Composites Application History for Aircraft Structures

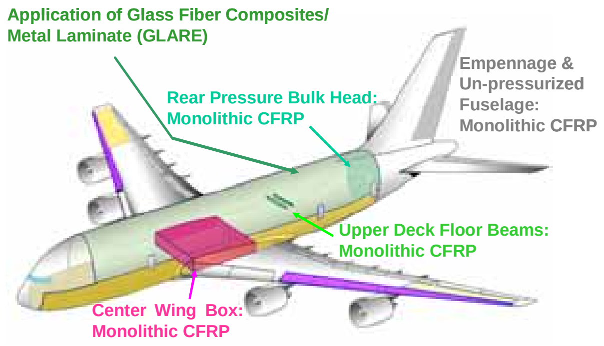


Fig. 2 Material Application Diagram in Airbus A-380

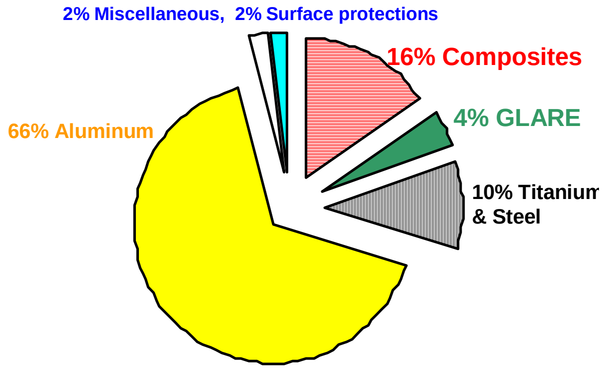


Fig. 3 Material Weight Ratio to Whole Structural Weight in Airbus A-380

mentions that the total of composites ratio is 23 % in this aircraft.

2.1 Importance of Composites Database and Standardized Test Method

Such a heavy utilization of composites to aircraft structures leads to a requirement of certification of composites structures as primary components. The route of the certification is well defined in the established composite handbook, US-based MIL-HDBK-17[3] as a "building block approach (BBA)" as shown in Fig.4. In BBA, establishment of complete and reliable composites database is the baseline activities where it must be accomplished in the shortest period and at the lowest cost. MIL-HDBK-17 nominates many test methods of composites characterization, ASTM (Test Methods by American Society for Testing of Materials) and SACMA (Supplier of Advanced Composite Materials Association, private organization in USA). Although a great number of tests based on these methods are conducted and they are already regarded as "*de facto*" methods, some of the methods include unreasonable points such as the usage of unnecessary size of the specimen or inappropriate loading fixtures. Particularly, unnecessarily larger size of the specimen makes the test costs quite high due to its great number of data for database generation. In some situation, new test methods for evaluation are required because traditional methods do not necessarily work due to improvement in composites property. In order to correspond these needs, JAXA ACE TeC is promoting new test method definition under some authorities in Japanese standardization system.

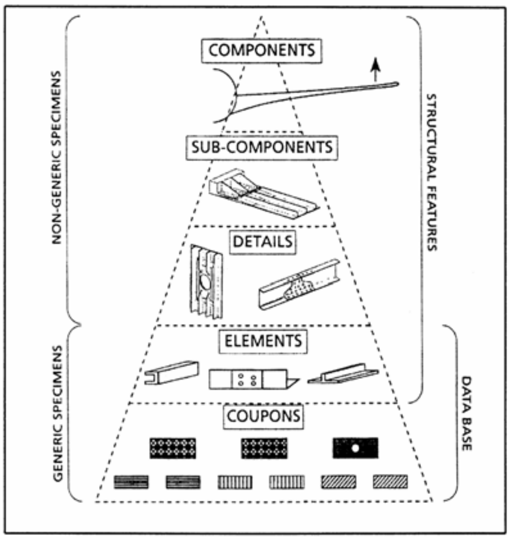


Fig. 4 Schematic of Building Block Approach for Composites Components[3]

3 Items under Standardization

3.1 Interlaminar Shear Strength Test by Double Notch Compression Method

Three examples of such activities will be explained here. The first example is considered as the latter case in the above-mentioned background. Due to the introduction of very tough composites such as translaminar reinforced composites, 3-D textile or stitching, typical traditional method for interlaminar shear strength (ILSS) tests based on short beam shear (SBS) do not work well for those new types of composites. In short, shear failure never happens in the extreme case. The alternative of wide spread SBS is a shear strength test method by using a double notch specimen. Although tension or compression may work equally if the fixture design is appropriate, compression is considered to be easier and to require smaller size of specimen. Thus, ACE TeC driven committee was formed to define the detail of the method at the fall of 2000. Several types of specimens were fabricated around the final candidate and distributed to nine organizations (industry, universities and government institutes) for round robin tests (RRT). All data were gathered together and the discussions for the method definition took place. The baseline specimen of 6.4mm notch distance and 1.0mm notch pit width is referred to as **MA** shown in Fig.5. Key issue other than specimen geometry was a torque effect of fitting screws, where two levels of normal torque (0.113 Nm) and its double was employed. Although the details are skipped, failure modes were checked and test results were compared with statistical analysis.

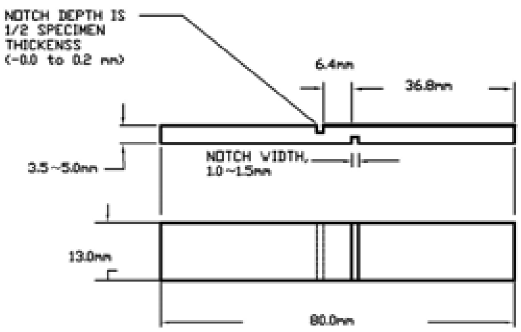


Fig. 5 Candidate Configuration of DNC JIS

Pictures of typical failure modes are shown in Fig. 6 where longer notch distance specimen (**LA**) does not fail in the pure shear mode and over depth specimen (**MA'**) exhibits mixed mode. They are not appropriate as standard specimen. Tests results of some parts of RRT conducted by ACE TeC/JAXA[4)] are shown in Fig. 7. Shorter notch distance specimen leads to lower strengths if its notch pit width is wide (1.5mm) and may not be compatible with the pitch of translaminar reinforcements. Thus, the middle distance of 6.4mm and both notch pit widths were selected as the candidate for JIS test method standard and it finally becomes identical with a candidate shown in Fig.5. Additional knowledge shown in Fig.7 is insensitivity of DNC strengths to screw torque if it remains up to a double level of the normal.

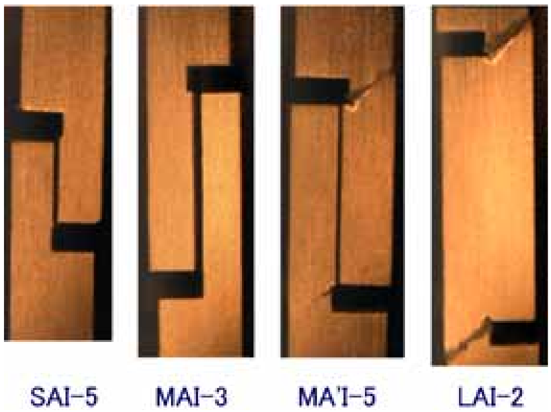


Fig. 6 Typical Failure Mode of DNC Tests

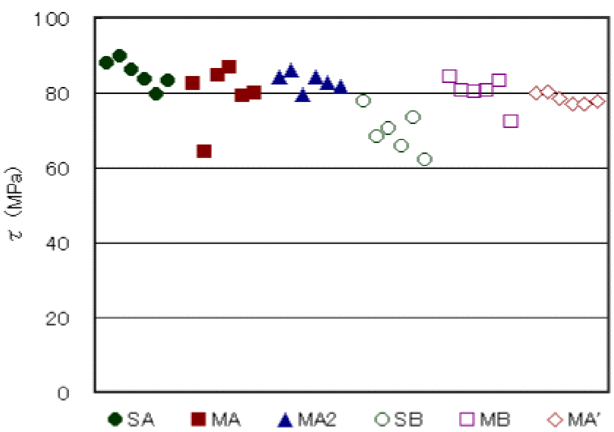


Fig. 7 DNC Shear Tests Results by ACE TeC (Part of Round Robin Tests)

By the present RRT, a draft for JIS standard of DNC shear test was already defined and ready for proclamation. Its essence is as follows: The specimen geometry is shown in Fig.5 and schematic of the tests including supporting fixture concept is shown in Fig.8. Clamping torque range and crosshead speed will be defined as 0.1 – 0.15 Nm and 1.0 – 2.0 mm/min, respectively. The detail is not described here.

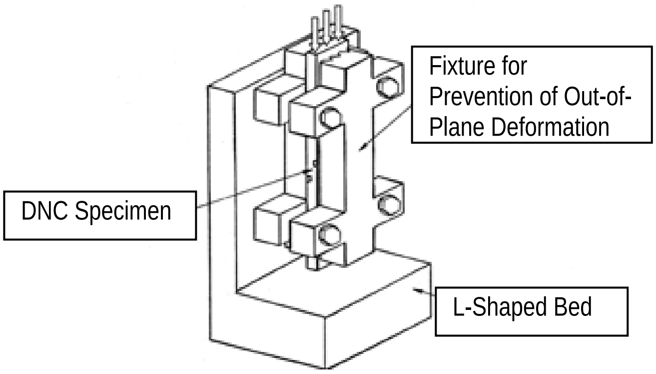


Fig. 8 Concept of DNC Shear Test Fixture and Test Itself in Proposed JIS

3.2 Open Hole Compression (OHC) Test

The open hole compression (OHC) test provides one of the most critical strength data among all coupon level tests. In some cases, this test results are considered to be a sort of measure of damage tolerance property of composites which is matrix driven and test cost is much less if we compare with it of compression after impact (CAI) test. So, the demand of this test is rising rapidly and reduction of test cost brings the big benefit in evaluation costs. Current "*de facto*" standard of SACMA SRM 3R-94[5)] is defined in MIL-HDBK-17 and used widely in USA and Japan. However, this method requires unnecessarily longer specimen of 304mm by 38.1mm probably due to the testing practice in USA circumstances. This large size of the specimen increases the test cost very seriously. So, the incentive for the standardization of OHC tests is to improve inappropriate nature of the *de-facto* test method of SACMA.

Based on this finding, ACE TeC developed new test method using shorter specimen and supporting fixture similar to ASTM D695 with rectangular window. This method is referred to as NAL-III following the old name of ISTA/JAXA, and its window size is maintained with SACMA 3R-94 fixture. The purpose of the window is to liberate out-of-plane deformation around the hole occurring before failure. Comparisons in specimen size and fixture configuration are shown in Figs. 9 and 10, respectively.

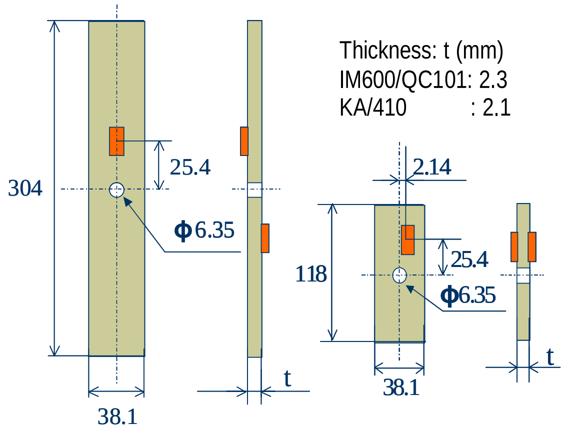


Fig. 9 Size of OHC Specimens: SACMA (Left) & NAL-III

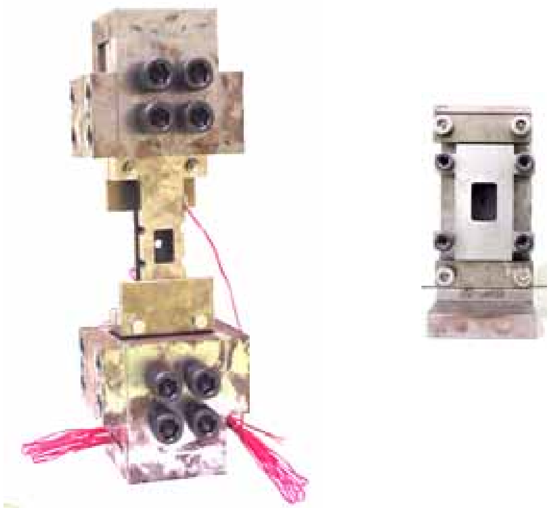
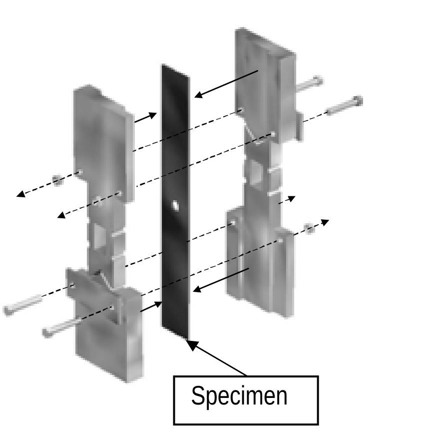


Fig. 10 Fixture of SACMA (Left) & NAL-III

Details of the fitting of the specimens into fixtures and their assembly schematics are shown in Fig. 11 for SACMA and Fig. 12 for NAL-III, respectively. To be exact, SACMA 3R-94 defines direct clamping of left set in Fig.11 into hydraulic grips of a testing machine as Method (I) and end loading using sub-fixtures of right set in Fig. 11 as Method (II).



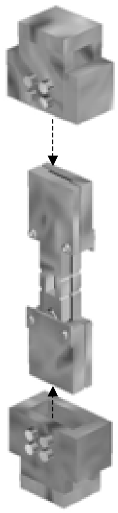


Fig.11 Specimen Fitting and Schematic of Fixture Assembly for SACMA OHC

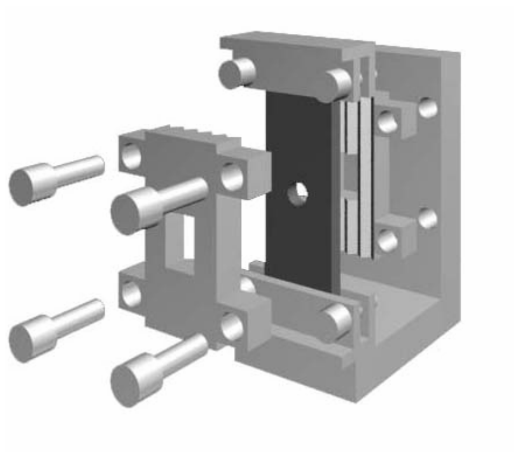
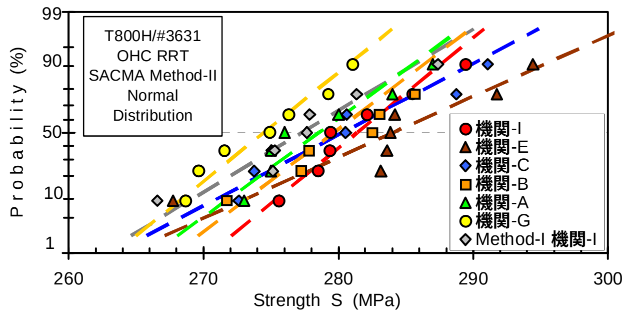
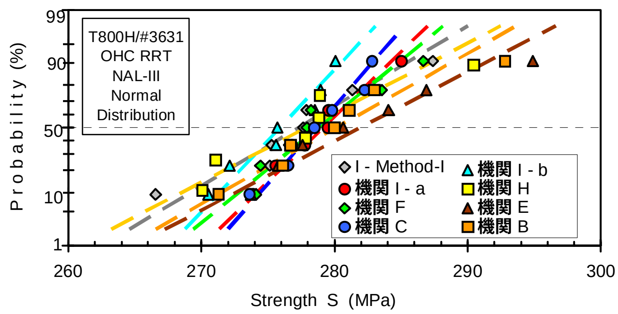


Fig.12 Specimen Fitting and Schematic of Fixture Assembly for NAL-III OHC

As shown in these figures, NAL-III method can provide not only shorter specimen but also simpler and lighter fixture with easy handling. Clamping devices are installed top and bottom of NAL-III specimen setting in order to prevent brooming failure at the end. Once the size and fixture definitions are completed, the next issue is a comparison of test results. Again, RRT's by 9 organizations were conducted by using both methods. Figure 13 depicts the results of RRT of OHC[6] for standard carbon/epoxy, T800/3631, where all the data are plotted on the normal distribution scale of abscissa. It can be seen that SACMA and NAL-III provide almost identical OHC strengths in average and that NAL-III provides much less scattered data indicated by steeper plot lines and by high density of the plot lines around 50% probability and the average strength. Such trends are also verified for other types of carbon/epoxy composites. It should be noted that the identical tests results to the existing *de facto* must be assured if the new method is proposed. Based on these findings, the committee decided that NAL-III is a valuable test method which can be one alternative of OHC test instead of SACMA. However, they do not reject the current *de facto* SACMA method, i.e., one of both tests could be chosen in this OHC JIS. The early draft of JIS has been written and it will be finalized in the near future.



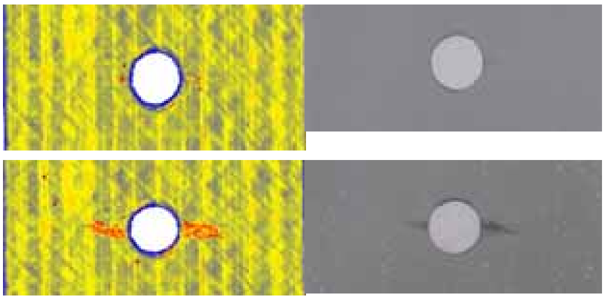
(b) Plots for SACMA Method



(a) Plots for NAL-III Method

Fig.13 Statistical Comparison in OHC Strengths by NAL-III & SACMA

Engineering verification why both methods lead to the similar result is not a complicated task. Figure 14 shows the trace of damage propagation by ultrasonic C-scan and x-ray radiography[7] during OHC tests for IM600/ QC101 CFRP system. It is very clear that the final failure propagates transversely to the load and no propagation to the longitudinal direction was found at all. This finding is very compatible with the no effect of upper and lower tongue portions of the specimens upon OHC strengths.

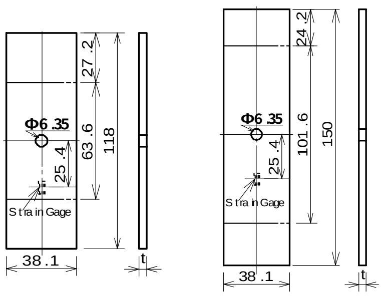


Left: Ultrasonic C-Scan, Right: X-Ray Radiography, Material: IM600/QC101 Upper Row: 19kN, Lower Row: 23kN

Fig.14 Damage Evolution in OHC Test

3.3 Open Hole Tension (OHT) Test

The other important test in composite database building is an open hole tension test (OHT). The current *de facto* test method, SACMA 5R-94[8], adopts the same geometry specimen as OHC, SACMA SRM 3R-94. So, the cost issue in the test again arises in OHT. A JAXA driven committee decided that the third target of standardization for JIS is OHT where important topic is a reduction in length. They selected three candidate specimen geometries as shown in Fig. 15 where the third long one is exactly identical with SACMA 5R-94.



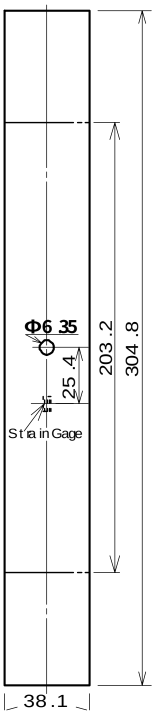


Fig.15 Current Plan of Specimen Geometry for OHT Round Robin Tests

If the damage evolution area remains outside of gripping zone of the specimens, no influence of the length on the failure mode and tensile strengths is expected. Confirmation of this speculation is the most important checkpoint in the RRT's. Those RRT's will start soon and the first draft of OHT JIS will be expected to be finished by next spring.

4 ISO Proposal Activities

4.1 Proposal of Compression after Impact (CAI) Test to ISO TC61/SC13

Compression after impact (CAI) test is another very important item for determination of design allowable strain levels in aircraft composite components. CAI tests provide usually critical design stress or strain in primary composite structures. Figure 16 describes a concept and major procedures how to do CAI tests. For this method, current "*de facto*" standard is defined again as SACMA SRM 2R-94[9]. On the contrary, JIS CAI methods established following SACMA 2R-94 in 1996 and the outline of those CAI test methods will be summarized in this article. The first key procedure is impact. The clamping device of rubber bush may be a point of future discussion. After impact, SACMA and JIS enforce non-destructive inspection of impact damage by ultrasonic C-scan. In European *de facto* standard which is a proprietary of Airbus Company, the measurement of impact dent is compulsory instead of ultrasonic C-scan.

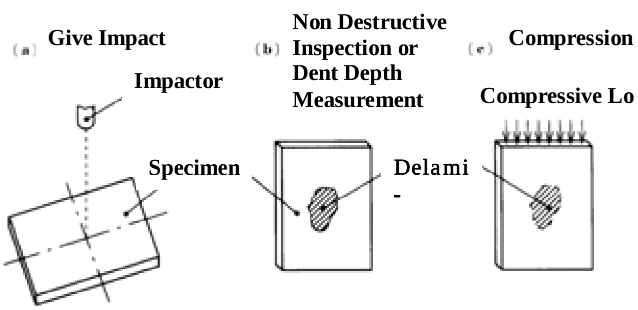


Fig.16 Concept and Procedure of CAI Test

This kind of deviation will be a discussing point in ISO/TC61 committee after proposal. If NDI or dent depth measurement is completed, the impacted specimen will be subjected by in-plane compressive load under the supporting fixture indicated in Fig.17. Boundary conditions shall be clamped at loading and supporting edges and simply supported at side edges. The concept of support and compression is quite similar in US/Japan and European current standards. The new work item for CAI test standardization has just approved in ISO TC61/SC13 committee by the effort of Japan's delegate and it will be exposed under sincere discussions for several years. Hopefully, it will consist a main frame of future ISO standards for this sort of important test method in composites structural application.

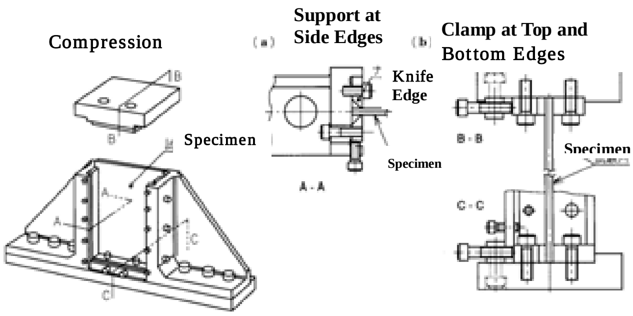


Fig.17 Concept of Compression Fixture

4.2 Proposal of Measurement Test of Elastic Modulus of Porous Ceramics to ISO TC207

Up to this point, all test methods to be standardized are related polymer matrix composites. Only this topic is related to test method of porous ceramics or porous ceramic composites. Due to their low elastic modulus, its measurement is quite difficult in porous fine ceramics and this difficulty is an incentive to establish elastic modulus JIS. Because JIS R 1659:2003, testing methods for elastic modulus of porous fine ceramics, was already defined and proclaimed in 2003, the governing organization of ISO related to fine ceramics and ceramic composites, Japan Fine Ceramic Association (JFCA) has decided to propose new work item of ISO standard to TC207 based on this new JIS R 1659. The proposal work is based on translation of JIS and some formatting, not accompanied by engineering work such as extra round robin tests. However, because this work remains still in the JAXA driven activity domain, this explanation is given here.

5 Conclusions

As the essential part of establishment of reliable and descriptive composite database, importance of test methods standardization for advanced composites has being raised and raised recently. Current status of such standardization efforts in Japan is reviewed and summarized in this paper. Before going to main body of the review, a background of such trends, broad applications of composites to commercial aircraft is explained.

Three test methods are under standardization into JIS, Japan Industrial Standard. JIS for interlaminar shear strengths by double notch compression has been just defined and to be proclaimed. JIS for open hole compression strengths is being discussed where a new test method invented in ACE TeC/JAXA (used to be National Aerospace Laboratory), NAL-III is evaluated and verified to be sturdy method. The first draft is already written and improvement will be finished in a year. The third method to be standardized into JIS is an open hole tension test. Round robin tests by 9 organizations will be started soon where three different lengths are compared.

Proposals of test methods of composites to ISO are also reviewed. Test method of compression after impact of carbon fiber reinforced plastics was proposed to ISO TC61 and adopted as a new work item. Test method of elastic modulus of porous ceramics or ceramic composites will be proposed soon.

In order to establish comprehensive and reasonable test methods, deep understanding of mechanics of behavior happening during tests is required. Not only such understanding of mechanics, engineering compromise between exactness and optimal cost performance in mechanical tests is also strongly required for establishing the widely accepted test methods. Typical examples of standardization undertaken in Japan are introduced here and they will be an important basis of wide application of advanced composites to aerospace fields.

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